

Interpersonal Biocybernetics: Connecting through Social Psychophysiology

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ABSTRACT

One embodiment of biocybernetic adaptation is a human-computer interaction system designed such that physiological signals modulate the effect that control of a task by other means, usually manual control, has on performance of the task. Such a modulation system enables a variety of human-human interactions based upon physiological self-regulation performance. These interpersonal interactions may be mixes of competition and cooperation for simulation training and/or videogame entertainment.

Categories and Subject Descriptors

H.5.2 User Interfaces: Input devices and strategies; B.4.2 Input/Output Devices: Channels and controllers.

General Terms

Design

Keywords

Physiological modulation, biofeedback

1. INTRODUCTION

The interpersonal biocybernetics concept is an extension of what may be termed an intrapersonal biocybernetics design. In the intrapersonal design, a participant's own physiological signals are made to influence or modulate their manual control of an interface. The intrapersonal design has been implemented by modulating manual videogame controllers and wireless motion videogame controllers.

A key characteristic of this design is the distinction between direct control and modulation of control. This distinction parallels the distinction made by Fairclough [2] between intentional brain-computer interface (BCI) operation and the biocybernetic adaptation paradigm that is based on spontaneous operator functional state. Physiological modulation of manual control differs from the conventional BCI practice of direct control of a task via physiological signals in an important way. A physiologically modulating system is a human-computer interaction system (HCI) designed such that physiological signals modulate the effect that control of a task by other means, usually manual control, has on task performance. In this way, physiological modulation integrates BCIs as intelligent sensors synergistically with the manual mode of control input.

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2. INTRAPERSONAL MODULATION

2.1 Software Modulation

The earliest embodiment of the physiological modulation concept was implemented in game software in a “space battle” scenario [7]. In this modulated prototype, a “difficulty adjuster” was programmed to vary according to an electroencephalographic (EEG) band power ratio, termed an “engagement index” [8]. In one mechanic, the subjective time of the game was correlated with the engagement index. Specifically, a delta time value was calculated based on the value of the EEG ratio. As this ratio value increased, the delta time, or dTime, decreased. This decreased value of dTime caused the subjective time of the game, i.e., the relative speed of target objects, to slow down, thus making it much easier for the player to hit targets and score points. The objective time of the game remained unaffected by the ratio level. Likewise, as the engagement index decreased, the relative speed of the target objects increased, thereby making the game more difficult and discouraging decreases in the engagement index. The player is thus encouraged to maintain a high ratio level since the game is easier and scores are improved. In addition to correlating the subjective time of the game with the ratio level, the prototype altered other parameters. For example, the normal operation of the selected video game introduced an effect termed jitter or evasiveness, which resulted in the position of the targets constantly changing in an unpredictable, seemingly erratic pattern, thereby increasing the difficulty of the game. This jitter effect was conventionally achieved by, e.g., calculating new X and Y positions for the graphic images using a randomly generated incremental change from the previous x and y values establishing position at a particular time. The EEG-modulated prototype inversely related the degree of this incremental change to the EEG band ratio level, i.e., the evasiveness decreased as the level increased and visa versa. In these ways, the player is encouraged to maintain high levels of the ratio index in order to succeed in playing the game.

This approach has the disadvantage of requiring extensive reprogramming of a video game, or the complete construction of a new video game, in order to implement the modulation concept. Because much video game software is proprietary and/or not available in source code, this approach would not be usable for implementing the interpersonal biocybernetics concept.

2.2 Hardware Modulation

Another approach [6] involves modulation that transforms the controller signals received at the computer's port prior to their being used by the computer simulation or game software. The result can be that the magnitude of the effect of the game or simulation's input device (e.g., joystick, game pad, steering wheel) is modulated by the strength of the physiological

signal(s). One implementation modulates the voltage powering a joystick axis in proportion to a physiological signal. By making the joystick's "control authority" proportional to the physiological signal, the player is encouraged to change the physiological signal according to a programmed criterion (e.g., increase, decrease, or maintain) in order to perform better at the game task. Another implementation pulse-modulates the button presses that a user makes on a controller. The frequency and/or width of the pulses is made proportional to the physiological signal, in effect, imposing a governor on the button's effect on the game or simulation by adjusting the effective closure time of the buttons.

A new type of controller allows a player to make inputs to a video game by moving the entire controller itself, thus requiring a different method of physiological modulation. One implementation exploits these motion-sensing technologies of the wireless Nintendo™ Wii™ videogame remote to modulate the player's movement inputs to the videogame based upon physiological signals. Prototypes of one design [4, 11] enhance the challenge of various games by physiologically modulated attenuation (motion-control dampening) and/or disruption (cursor control perturbation). Games and simulations that are appropriate for this manipulation include first person shooter games using crosshairs position and point of view perturbations, medical simulations that use surgical instrument position perturbation based on autonomic measures reflecting anxiety to teach stress management during medical procedures, and sports simulations that adjust golf stroke strength based on electroencephalographic signals reflecting concentration.

These modulation influences can emulate the amplification of nervousness when performing a task under pressure or the increase in the likelihood of error when becoming bored. Or, on the other hand, the enhancement of manual ability when performing a task "in the zone."

In one embodiment, the standard sensor bar of the Wii™ video game system is replaced with an array of infrared light-emitting diodes (LEDs) that are individually controllable on and off. This embodiment turns LEDs in the array on and off in dynamic patterns to produce a disturbance in the player-directed control of the infrared-sensing videogame controller, resulting in a disruption in the stability of the player-controlled object (e.g., a cursor) on the screen. The degree of the disruption is programmed to be proportional to the difference between the player's current momentary physiological signal value and a pre-selected target value. In this way, the player is rewarded for diminishing this difference by an improved ability to accurately position the player-controlled object (e.g., a cursor) on the screen.

A microcontroller samples amplified and processed physiological signals (e.g., cardiometer readings), tests the signal levels with programmed conditional instructions, and, in accordance with the physiological signal condition determinations, adjusts the degree of the disruption. A similar scheme dynamically adjusts digitally controlled potentiometers that are configured as voltage dividers to modulate the voltage from the battery supply that powers the controller accelerometers and/or gyroscopes. This manipulation is intended to enhance the challenge of various games by physiologically modulated attenuation (dampening) of a user's motion input (e.g., golf stroke), providing an incentive to produce the target physiological signal(s).

3. INTERPERSONAL MODULATION

Extending intrapersonal modulation to the interpersonal domain is intended to catalyze interaction among participants around physiological self-regulation performance challenge. These interpersonal interactions may be mixes of competition and cooperation for simulation training and/or videogame entertainment.

Physiological modulation technologies that operate by altering the functioning of game controllers, i.e., externally to game consoles, may be readily set up to allow players to interact with the game, and compete with each other, on a psychophysiological level, adding a new dimension to play – as well as expanding the skill set required. Competitive interaction with these intrapersonal modulation functionalities may be implemented with the standard multi-player capability of off-the-shelf game systems.

However, a multiplayer format is also envisioned wherein physiological self-regulation skill contributes to success in ways analogous to traditional game-playing skills, i.e., scoring, power-ups, etc.

3.1 Multi-User Modulation Design

Norris [5] pointed out that:

Top athletes [...] make excelling in their chosen type of psychophysiological control of the craniospinal system and striate muscles the major focus of their efforts. Here in the West, we value objectivism, material things, and have turned our attention outward toward controlling the external world. In the East, it has been quite different; the orientation of science and society values subjectivism and numinal experiences, and they have turned their attention inward, toward control of the internal world. Therefore, their champion 'acrobats' are those individuals who can assert and demonstrate control over autonomic and other internal processes. [...] in India, they have a sort of autonomic Olympics, where yogis and adepts come from far and wide to demonstrate their prowess at such things...

In the present day, this sort of event could take place in a multi-player environment such as a videogame tournament.

The design of a psychophysiological competitive, as well as cooperative, environment is proposed in "Physiological Interface for a Multi-User Virtual Environment (MUVE) [9] intended to augment "a computer user's sense of immersion in the computer-generated multi-user virtual environment by adding physiological interactivity to the multi-user virtual environment and by influencing the scoring of performance in the multi-user virtual environment with measured values of a user's physiological functions" (e.g., an EEG-based engagement index [8]).

The aim is to make any multi-user videogame or multi-user computer-simulated task more engaging and hence more effective as a device for teaching physiological self-regulation, by incorporating, as a competitive or cooperative interactive feature, each user's ability to self-regulate aspects of his or her physiology.

This MUVE design is intended as an enhancement of multiplayer videogames that computes physiological scores standardized on an individual's baseline responses - to level the playing field, and compares a selected score with a benchmark target or benchmark normative value. Depending on the results of the comparison, at least one game consequence is selected which may take various

forms: a change in a user's point score; or a change in some element in the MUVE, i.e., a "power element" that is important for further success, such as the accrual of virtual fuel, food, ammunition, energy, longevity, shielding; or, a change in some virtual power, capability or function of a user's avatar that is important for further success, such as range of motion, or effect of motion, or duration of activity; or the user's control of the MUVE control input device may be made more or less difficult. Based on the user's performance, game consequences may also take the form of similar competitive or cooperative consequences for the user's opponents or teammates. Each consequence may be made proportional to a functional combination of physiological comparison values.

Additionally, a user may qualify for a gain of a certain advantageous element or game privilege only if the user has attained a threshold score that has been defined for that element or privilege. For example, upon attaining a threshold score, a player may selectively donate or withdraw performance points to or from the score of each other user interacting with the MUVE, adding an additional competitive or a cooperative aspect to the interaction.

One component of a user's performance is determined by each user's skill in using an input device to control the actions of his or her avatar in various scenarios and encounters arising within the MUVE, such as the outcome of combat with an enemy avatar in a videogame embodiment of a MUVE, or the outcome of a cooperative effort with a teammate avatar in a computer-simulated task embodiment of a MUVE. A second component is determined by each user's skill in self-regulating his or her own physiological functioning while controlling his or her avatar using an input device. The second component reflects the competition or cooperation engaged in by each user of the MUVE using measured values of his or her physiologic functions.

A player's physiological performance record accrued in the course of a session in the physiologically modulated MUVE may subsequently be accessed by software or another user. For example, the physiological performance record may subsequently be assigned to another "assignee" avatar whose behavior in the MUVE is thereafter determined and controlled by utilizing the player's performance record, and the player's avatar may be activated while the player is not participating in the MUVE. The assignee avatar assumes the recorded physiological performance of the absent player, and emulates the player's recorded physiological reactions to certain events occurring in the MUVE, such as parrying a sword thrust, thereby effectively serving as a "ghost" of the player with which other users of the MUVE may interact in the absence of the player's actual participation in the MUVE.

3.2 Collaborative Modulation Design

The entertainment value and social interaction experience of electronic gameplay may be enhanced by distributing the control and modulation of inputs to electronic games among two or more players, so that joint game goals are collaboratively pursued and accomplished by separate players who provide different means of control and modulation [10]. For example, one or more players may provide physical activity control via game controller(s) (these players may be termed the physical operators) and one or more other individuals influence the game through physiological activity measured via body sensors (these players may be termed physiological operators). When applied to neurofeedback

training, such collaboration encourages the therapist or parent to provide social support by engaging in a training session as the physical operator, while the trainee practices self-regulation as the physiological operator. In a training simulation context, collaboration would consist of a physiological operator (e.g., the pilot-monitoring) practicing a psychophysiological state associated with sustained attention while the physical operator (e.g., pilot-flying) practices manual operation. This interdependent mode of operation could provide novel material for the communication aspect of crew resource management (CRM) training [3].

Some physiologically modulated game designs [6, 7, 11] lend themselves readily to collaborative interaction by having different players assume the physical and physiological operator roles with the same modulated controller [10]. Such an embodiment avoids the problem of movement disruption of physiological sensing by modulating one player's game controller using the physiological signals of another, collaborating player who is physically inactive. This functionality further enables collaborative team play by multiple players with different roles on the team - one or more providing physiological mastery to facilitate game performance and one or more others simultaneously providing manual or physical skills needed to operate the game. This creates richer and more complex gaming opportunities than present games provide, enabling engaging and rewarding team social interactions among people who have different skill sets and interests or who take turns playing different roles on a team - either providing the physiological self-mastery skill or providing physical performance action skills.

This design modulates one or more players' game controller (i.e., game input device operated by physical activity) using the physiological signals of another/other collaborating player(s) who is/are not providing input to the game via a game controller. This function is accomplished by transmitting control signals, either wired or wirelessly, derived from one or more players' physiological signals to modulate the control over the game of one or more other players who are using electronic game controllers, in a way that either limits or boosts the game performance influence of the game controllers.

Alternatively, this shared influence over a game of a physiological operator and physical (game controller) operators can be implemented by blending influences from both into a single control input into the game; in this manner, game action tasks could be operated either via a game controller or particular predefined physiological input, or through pre-defined combinations of both. For instance, a video game task of an avatar game character jumping over a canyon could be initiated by either the game controller operator or by a physiological operator's particular body activity, and the height or length of the jump could then be solely dependent on the physiological activity of the physiological operator whereas the direction of the jump and place of landing on the other side could be controllable only by the game controller input. Thus, the physiological and game controller operators would have to collaborate to succeed at the task of jumping for success in the game.

Two new categories of electronic game play are made possible: 1) modulating one or more player's game controller input using the physiological signals of another/other collaborating individuals; and 2) modulating game activity through joint authority over game actions by game controller input from one or more individuals and physiological sensor input from other separate individuals not using game controllers. Physiological

and manual control of electronic games can be allocated in various combinations to several players.

Individuals who are physically challenged may participate in electronic game play by collaborating with a player who is able to manipulate controls that the challenged player cannot, and enables individuals with different skill sets and interests (physiological self-control vs. physical performance skills) to join together in rewarding game play.

Unprecedented electronic games can be created that incorporate a classic motif in superhero comics and movies in which differently-abled protagonists collaborate and/or interact, such as Professor X and his cohorts in the X-Men series, and provides opportunities for new kinds of games where the application of "mental powers" of particular individuals (e.g., particular deliberately produced EEG characteristics) can enable or enrich the performance of other individuals playing a game.

4. DISCUSSION

Certain human physiological states are associated with the optimal performance of certain activities and behaviors, or the attainment of superior states of health. Biofeedback training directed to self-regulating such physiological states seeks to optimize the performance of their associated actions, behaviors, and states of health, thereby facilitating mastery in action and well-being. For example, a self-induced reduction of an elevated heart rate and blood pressure, a rise typically associated with anxiety, may be expected to move a person into a state of superior focus with respect to a challenge and its resolution - a state that is better suited for victory over an opponent in real or simulated combat or completion of a real or simulated task [1].

Biofeedback training techniques for physiological self-regulation are fundamentally grounded upon repetition and the frequency of repetition, techniques for which persons have varying and limiting tolerances, particularly if their practice of biofeedback is undertaken in an environment that is not motivating because it fails to engender excitement, enthusiasm, challenge, stimulation, or curiosity. The absence of such motivating feelings can result in nonadherence to biofeedback training - a persistent and pervasive problem that has limited the prevalence and effectiveness of biofeedback training.

However, biofeedback training programmed into videogames or computer simulations has been limited to single-user videogames or single-user computer simulations, where the user is made aware of only some of his or her own monitored physiological functions, and the user's interaction with the videogame or computer simulation is modulated only by the control of his or her own physiological functions [6, 7, 11]. In effect, the user competes only with himself or herself, and this may limit commitment to play and participation, with a concomitant decline in biofeedback-mediated self-regulation of the user's physiological state.

Recent biofeedback technology innovations have solved this problem to a degree, by blending biofeedback into videogames, and thereby making training inherently motivating.

On the other hand, physiologically modulated videogame or computer simulation systems also enable a variety of human-human interactions based upon physiological self-regulation performance. These interpersonal interactions may be mixes of competition and cooperation for simulation training and/or videogame entertainment.

Physiologically modulating games and simulations has the effect of projecting exaggerated effects of the physiological concomitants of emotion and cognition into the interaction. Incorporating social interactivity into physiologically modulated games and simulations further engages users in human-computer interaction experiences that have the capacity to train valuable mental skills beyond hand-eye coordination.

When physiological signal(s) are the target of physiological self-regulation or biofeedback training, modulated game play reinforces therapeutic changes in related physiological processes. However, the reinforcing feedback is implicit in the game play and not explicit in the form of direct feedback (bar graphs, tracings), as in conventional biofeedback training. In this way, contingencies for subtle conditioning of the desirable physiological response(s) are set up.

The added benefit of the physiologically modulated approach is the improvement of self-regulation capabilities that directly impact a player's health in a positive manner. Videogames and simulations can be designed such that success in the virtual world is predicated upon self-regulation skills demonstrative of healthy autonomic function and optimal cognitive states. Evoking certain psychophysiological states is a design choice that developers are currently making de facto, but with the result that games and simulations are often devices that produce frustration and foster poor attention abilities. The decision by designers to incorporate physiological modulation can be considered a next step in a more informed and healthy direction for gaming and simulation products. Making this choice allows users to choose technology that is entertaining as well as beneficial to their physical, mental and interpersonal health.

The approaches to physiological computing described in this paper represent a unique blending of conventional computer interface capabilities with contemporary psychophysiological monitoring and biofeedback techniques. The use of physiologically modulated videogames and simulations involving multiple players using traditional manual control and BCIs as intelligent sensors promises to augment HCI and human-human interaction (HHI) applications. Tapping into the natural social experience that occurs when players compete or collaborate in gaming or simulated environments leverages subtle interpersonal interactions. The addition of the challenge of physiological self-regulation in a social context improves the motivation to perform in order to enable team success or victory over opponents in simulated environments. Further, implementing this challenge in the ways described herein fosters dialogue around self-regulation among the participants. These implementations can require dividing attention between one's own self-regulation performance and that of others, a potentially valuable skill for team settings.

How an interface can adapt to the user to provide support is an important consideration for BCI research. Current BCI technology has specific application and usability goals at the fore. Establishing reliable capabilities is of foremost importance, but, beyond utility, these systems can be designed to inherit the benefit of social experience that occurs between humans. The application of readily available physiological information from BCI technology can be used to enable such a user experience.

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